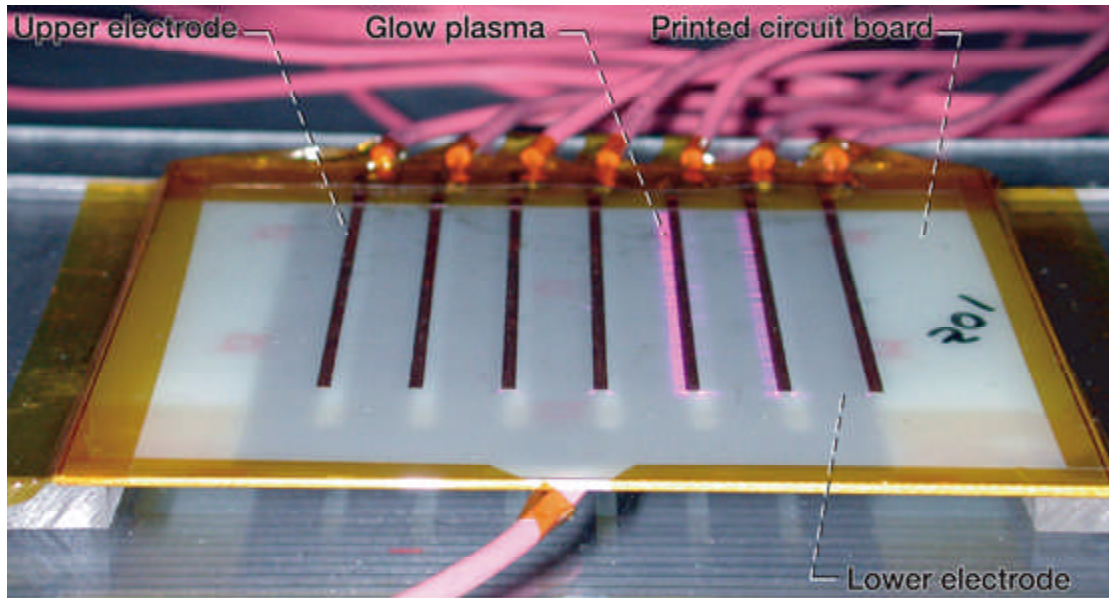


Glow Discharge Plasma Demonstrated for Separation Control in the Low-Pressure Turbine

Flow separation in the low-pressure turbine (LPT) is a major barrier that limits further improvements of aerodynamic designs of turbine airfoils. The separation is responsible for performance degradation, and it prevents the design of highly loaded airfoils. The separation can be delayed, reduced, or eliminated completely if flow control techniques are used. Successful flow control technology will enable breakthrough improvements in gas turbine performance and design.

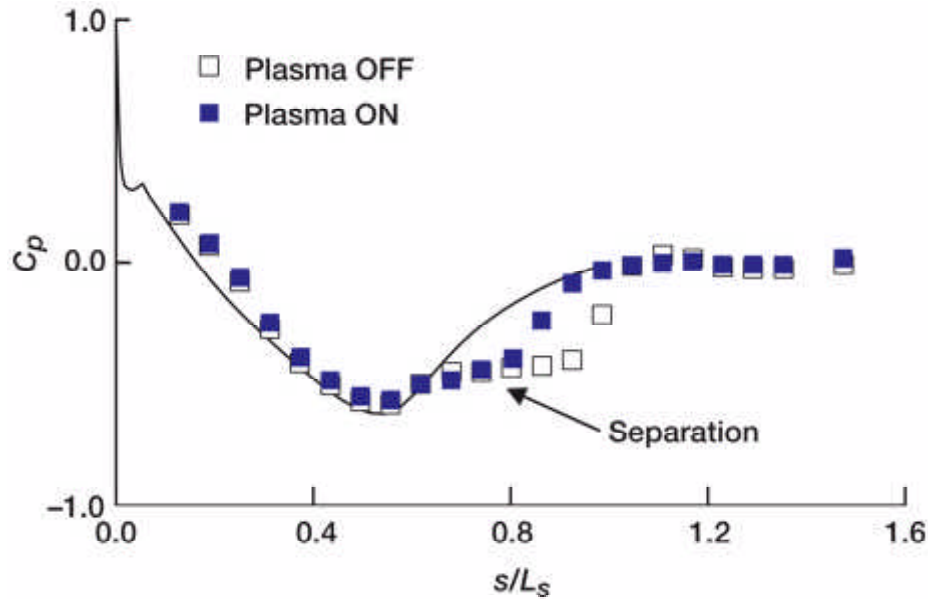
The focus of this research project was the development and experimental demonstration of active separation control using glow discharge plasma (GDP) actuators in flow conditions simulating the LPT. The separation delay was shown to be successful, laying the foundation for further development of the technologies to practical application in the LPT.

In a fluid mechanics context, the term "flow control" means a technology by which a very small input results in a very large effect on the flow. In this project, the interest is to eliminate or delay flow separation on LPT airfoils by using an active flow control approach, in which disturbances are dynamically inserted into the flow, they interact with the flow, and they delay separation. The disturbances can be inserted using a localized, externally powered, actuating device, examples are acoustic, pneumatic, or mechanical devices that generate vibrations, flow oscillations, or pulses. A variety of flow control devices have been demonstrated in recent years in the context of the external aerodynamics of aircraft wings and airframes, where the incoming flow is quiescent or of a very low turbulence level. However, the flow conditions in the LPT are significantly different because there are high levels of disturbances in the incoming flow that are characterized by high free-stream turbulence intensity. In addition, the Reynolds number, which characterizes the viscous forces in the flow and is related to the flow speed, is very low in the LPT passages.



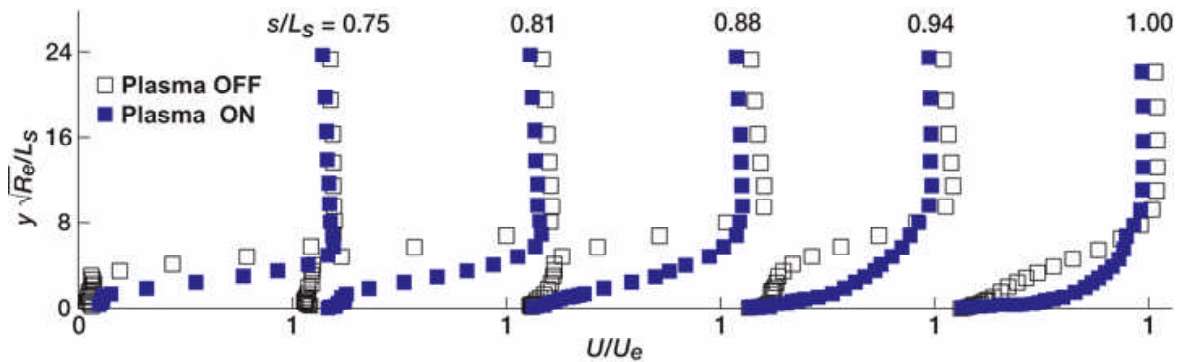
Glow discharge plasma actuator.

This work focused on using GDP actuators. These are innovative devices that generate flow disturbances. Electrodes on the surface, powered by high alternating-current voltage, create a type of plasma called glow-discharge plasma. The plasma creates a body force in the air near the surface. By proper design and operation of the electrodes, flow disturbances are inserted into the flow. A GDP actuator was fabricated on an electronic circuit board and was flush mounted on a test flat plate in Glenn's CW-7 transition research wind tunnel, which was equipped with an insert to simulate the pressure distribution on the suction surface of an LPT airfoil. A computer-controlled electronic driver system was designed and built. It employs operational amplifiers and custom transformers and can supply eight channels with 12 kV at up to 15 KHz. The actuator, which was operated as a phased array, was based on an idea developed by Corke (ref. 1). It generated an oscillating wall jet at a frequency in the range of instability waves associated with a separation bubble. The boundary layer was measured using surface pressure taps and hot-wire anemometry. Using hot-wire anemometry in the presence of ionized air required special attention. The system was protected from electric charge associated with the GDP by using optical links and a custom low-capacitance isolation transformer and by floating all the electrical grounds. Measurements were made for several Reynolds numbers and free-stream turbulence levels.



Pressure distribution on surface, indicating that when the plasma is ON the separated region is decreased. Reynolds number, Re , 50,000; turbulence intensity, TI , 0.2 percent; streamwise coordinate, s ; reference length, L_s .

This project was the first to demonstrate that GDP phased-array actuators are an effective technique for separation delay in LPT flow conditions. In addition, it was the first time that hot-wire measurements were made in presence of glow discharge plasma. It was first set of direct measurements inside the boundary layer verifying the effect of GDP actuators. The work is described in detail in Hultgren and Ashpis (refs. 2 and 3). It represents Glenn's contribution to a cooperative agreement with the University of Notre Dame. The results are being used in experiments with GDP flow control on an LPT cascade there (ref. 4).



Velocity profiles at selected stations. The inflected profiles with white symbols indicate separated flow without control. The profiles with GDP actuators ON (black symbols) are full profiles indicating attached flow. Reynolds number, Re , 50,000; turbulence intensity, TI , 0.2 percent; normal coordinate, y ; streamwise coordinate, s ; reference length, L_s ; velocity, U ; free-stream velocity, U_e .

References

1. Corke, Thomas C.; and Matlis, Eric: Phased Plasma Arrays for Unsteady Flow Control. AIAA Paper 2000-2323, 2000.
2. Hultgren, Lennart S.; and Ashpis, David E.: Glow Discharge Plasma Active Control of Separation at Low Pressure Turbine Conditions. Bull. Am. Phys. Soc., vol. 47, no. 10, 2002, pp. 167-168.
3. Hultgren, Lennart S.; and Ashpis, David E.: Demonstration of Separation Delay With Glow-Discharge Plasma Actuators. AIAA Paper 2003-1025 (NASA/TM--2003-212204), 2003. <http://gltrs.grc.nasa.gov/cgi-bin/GLTRS/browse.pl?2003/TM-2003-212204.html>
4. Huang, J.; Corke, T.; and Thomas, F.: Plasma Actuators for Separation Control of Low Pressure Turbine Blades. AIAA Paper 2003-1027, 2003.

Glenn contact: Dr. David E. Ashpis, 216-443-8317, ashpis@nasa.gov

Authors: Dr. David E. Ashpis and Dr. Lennart S. Hultgren

Headquarters program office: OAT

Programs/Projects: SEC, DDF, UEET, Propulsion and Power, VSP, Twenty-first Century Aircraft Technology